Galactic nuclei formation and activity induced by globular cluster merging

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Abstract. Different types of observations, together with consistent and physical modelizations, suggest as realistic the hypothesis of enrichement of galactic nuclei by mean of massive globular clusters orbitally decayed and merged in the inner regions of early type galaxies. In this context, the scenario of globular cluster mergers and subsequent formation of a dense Super Star Cluster in the center of a triaxial galaxy is presented and discussed, together with its astrophysical implications, including that of massive black hole feeding and accretion in the center of a triaxial galaxy.

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INTRODUCTION

The Hubble Space Telescope and large ground based telescopes are providing an impressively increasing amount of data concerning Globular Cluster Systems (GCSs) in galaxies, mainly of the early types, since the pioneering work [19].

Two are the most relevant and well defined observational points: (i) the difference in the GCS and galaxy light spatial distribution, and, (ii) the existence of a bimodal color distribution for GCSs, and the possible differences between the *blue* and the *red* population,

Here I will not discuss about point (ii) (see the recent [27] paper) but just about point (i) whose solution implies an 'evolutionary 'interpretation which has relevant astrophysical implications.

THE GCS RADIAL DISTRIBUTIONS IN GALAXIES

Presently available observations indicate clearly that the majority of galaxies shows a radial profile of their GCS shallower than that of the stars toward the galactic centre (see, for instance, Fig. 1). Actually, ellipticals have usually a stellar profile peaked toward the galactic center (many have a 'cuspy' profile, indeed), while the GCS radial distribution shows, usually, a core. Among the many papers about this topic, we limit to recall [18],[17]. This difference in the density profiles has an interpretation either in terms of formation and evolution of elliptical galaxies (see [20], [17], [1], [3]). or in terms of evolution of the GCS itself (see [4], [13], [14]).

The explanation on the basis of GCS evolution is more appealing, because much simpler and not based on qualitative and arbitrary modelizations of GC formation in galaxies. Moreover, it has other important astrophysical consequences, allowing to give an answer

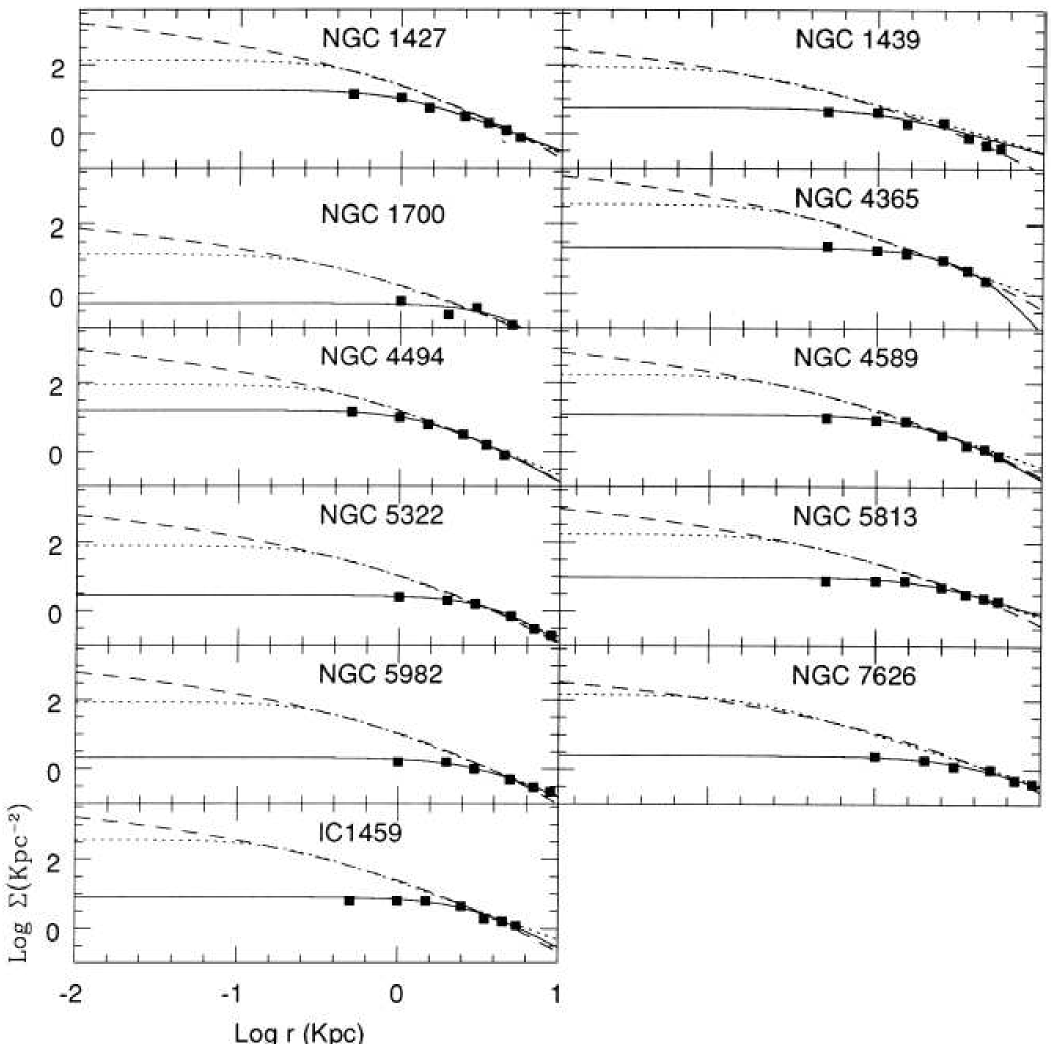

FIGURE 1. Surface number densities for the galaxies of the [17] sample. Black squares represent the observed globular cluster distribution; the solid line is its modified core model fit. Dashed and dotted lines are de Vaucouleurs and modified core model fits to the normalized galaxy profile, respectively. The figure is taken from [13].

to the open question of the origin of the matter enriching massive black holes in the center of active galaxies.

GCS evolution

The evolutionary view sketched above is remarkably simple because it bases just upon the, quite reasonable, hypothesis that the GCS and the halo-bulge stars in the galaxy are coeval and had, initially, the same radial density profile. Under this assumption, the presently observed different distributions should be caused by evolution of the GCS,

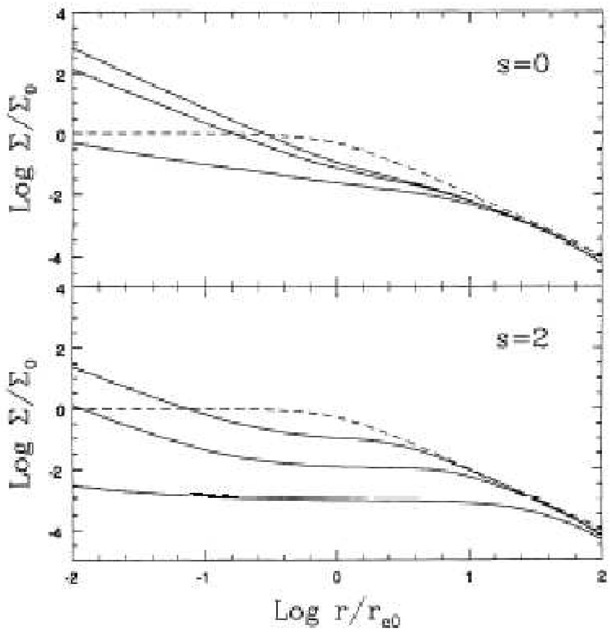

FIGURE 2. Plot of the GCS surface density profile after evolution has occurred for a flat (s=0) IMF of the GCS (upper panel) and for a steep (s=2) IMF (lower panel). The dashed curve is the initial profile; the other curves correspond to nuclear masses of $!0^7$, 10^8 and 10^9 $M_\odot$ (top to bottom). The figure is taken from [12]

respect to the unevolved, collisionless, halo-bulge stellar component.
That GCSs in galaxies undergo an evolution is undoubtful, because they are massive, evolving aggregates of stars moving in an external potential which influences the system by both dynamical friction and tidal distortion. A detailed analysis of the GCS radial profile evolution in early type galaxies under the combined influence of dynamical friction and tidal disruption, mainly caused by a massive central black hole (bh), has been presented in [13] where a quantitative explanation of the observed comparative features of GCS' and stellar light profiles is given. Fig. 2 shows the the expected projected GCS radial profile under the combined influence of dynamical friction and tidal disruption (this latter mainly caused by a massive central black hole), after an evolution of the GCS up to a Hubble time

Some researchers have invoked one observational feature, the GCS radial distribution being shallower for brighter galaxies than for faint ([17]), as evidence against the 'evolutionary' explanation.
Apart from that the claimed correlation is not universal (for instance, [2] found a quite shallow GCS radial distribution in the Virgo dE VCC 1087), the evolution of a GCS due to the combined role of dynamical friction, acting on the large scale, and nuclear tidal distortion, on both the large scale of the overall field star distribution and on the smaller one of the compact galactic nucleus, leads to a positive correlation between the core radius of the GCS radial profile and the galaxy integrated luminosity exactly as observed (see Fig. 3, left panel), which is clearly due to the increasing (with time) GCS

TABLE 1. The presently observed number of clusters (N), its initial value (N_0), its fractional variation ($\Delta N/N_0$), the mass lost in form of disappeared globulars (M_l). Data are from [8], [13], [9] and [11]. The galaxy integrated magnitude (M_V) and central black hole mass (M_{bh}) values are from the literature.

Galaxy	M_V	M_{bh}	N	N_0	$\Delta N/N_0$	M_l ($M_\odot$)
Milky way	-20.60	2.60×10^6	155	211	0.27	1.80×10^7
M 31	-19.82	2.30×10^7	283	368	0.23	2.30×10^7
M 49	-23.10	5.00×10^8	6321	13080	0.52	2.23×10^9
M 87	-22.38	3.61×10^9	4456	8021	0.44	2.33×10^9
NGC 1379	-20.16	-	132	512	0.74	1.50×10^8
NGC 1399	-21.71	5.22×10^9	5168	9680	0.63	1.44×10^8
NGC 1400	-20.49	-	83	233	0.64	4.95×10^7
NGC 1404	-20.49	-	508	1061	0.53	1.75×10^8
NGC 1407	-21.77	-	317	407	0.22	3.40×10^7
NGC 1427	-20.43	1.17×10^8	248	487	0.49	8.86×10^7
NGC 1439	-20.40	1.95×10^8	130	141	0.08	4.79×10^6
NGC 1700	-21.52	4.37×10^9	25	39	0.36	3.66×10^6
NGC 3258	-21.40	1.00×10^9	305	512	0.40	6.80×10^7
NGC 3268	-21.96	-	519	909	0.43	2.29×10^8
NGC 4365	-22.06	7.08×10^8	517	849	0.39	7.48×10^7
NGC 4374	-22.62	1.00×10^9	4731	7177	0.34	8.20×10^8
NGC 4406	-22.30	1.40×10^8	2834	4192	0.32	4.10×10^8
NGC 4494	-20.94	4.79×10^8	200	297	0.33	2.98×10^7
NGC 4589	-21.14	3.09×10^8	241	371	0.35	7.58×10^7
NGC 4636	-21.71	-	1426	2149	0.34	1.55×10^8
NGC 5322	-21.90	9.77×10^8	175	266	0.34	6.51×10^7
NGC 5813	-21.81	2.82×10^8	382	596	0.36	1.03×10^8
NGC 5982	-21.83	7.94×10^8	135	260	0.48	8.86×10^7
NGC 7626	-22.34	1.95×10^9	215	365	0.41	3.59×10^8
IC 1459	-21.68	2.60×10^8	271	516	0.47	1.57×10^8

core radius size showed in the right panel of Fig. 3, which depends on that the central galactic bh mass increases with time. To conclude, the GCS slope vs. galaxy luminosity correlation is not, unfortunately, a way to distinguish between the two above mentioned hypotheses (compare left panel of Fig. 3 with Fig. 4 in [3]). Anyway, it is relevant noting that the correlation found in [3] relies on ad-hoc assumptions, which the evolutionary scheme is free from.

Mass loss from the GCS

Under the hypothesis that the flatter, respect to field stars, central distribution of GCs is due to evolution and subsequent depauperation, it is possible to evaluate the number of 'lost' GCs by the difference of the actually observed GCS radial profile and that of the bulge-halo stars, which is considered as representative (after a linear scaling) of the GCS initial distribution. This exercise was done for the first time by [16], who estimated

an upper limit on the total mass which could have been removed from the M87 globular cluster system, yielding a value (7.6×10^8 M$_\odot$) which is less than 30 % of the size of the compact nucleus (supermassive black hole) in M87. A much more detailed study [8] of this giant elliptical, as of the Milky Way and M 31, gave, instead, a much higher value for the M87 GCS mass lost to the center, $M_l \approx 2.3 \times 10^9$ M$_\odot$, i.e. $\sim$ 65% of the M87 bh mass. On this line, [13], [9] and [11] deduced values of the number and mass lost by GCSs in several galaxies where good photometric data are available.
Table 1 is an enlargement of what presented in [6] and [9] to a set of 8 other recently studied GCSs ([11]) . It resumes these old and new results on the number (N_l) and mass lost in form of centrally decayed GCs, giving also the asbolute integrated magnitude of the host galaxy and, when available, the central bh mass. The M_V and M_{bh} values are collected from the literature and their discussion is postponed to a forthcoming paper [11]. It is evident from data in the Table that the fraction (in number) of GCS eroded during a Hubble time is significant, ranging from 22% of NGC 1407 to 74% of NGC 1379. Fig. 4 shows the existence of a correlation between M_l and M_V and between M_l and M_{bh}. The least-square fits to the data are

$$LogM_l = -0.5059 M_V - 2.8592, \tag{1}$$

with rms= 0.5124 and $\xi^2 = 6.5627$, and

$$LogM_l = 0.2931 LogM_{bh} + 5.5461, \tag{2}$$

with rms= 0.2831 and $\xi^2 = 5.5461$. The large dispersion in Fig. 4 is mainly due to inomogenheity of M_V and M_{bh} data, which deserves a more careful discussion. This is quite interesting because it corresponds to a correlation of the GCS mass lost with both the *large* and the *small* scale structure of the galaxy. This is indeed what expected in the frame of the evolutionary picture, as it is better explained in the following.

SUPER STAR CLUSTER FORMATION AND NUCLEUS ACCRETION

There is growing evidence of the presence of very massive young clusters, up to the extremely large mass of W3 in NGC 7252 ($M = 8 \pm 2 \times 10^7$ M$_\odot$, [25]). Massive clusters are, too, a significant fraction of galactic GCs: actually, [21] indicates how up to a 40% of the total mass in the GCS of brightest cluster galaxies is contributed by massive GCs (present day mass $> 1.5 \times 10^6$ M$_\odot$), in good agreement with recent theoretical results by [22].

The initial presence of massive clusters in a galaxy makes particularly intriguing the GCS evolutionary frame sketched in the previous Sections, because the presence of some massive primordial custers may have had very important consequences on the initial evolution of the parent galaxy. Actually, the GCS evolution in an elliptical galaxy naturally suggests the following *scenario*:

(i) massive GCs on box orbits (in triaxial galaxies) or on low angular momentum orbits (in axisymmetric galaxies) lose their orbital energy rather quickly;

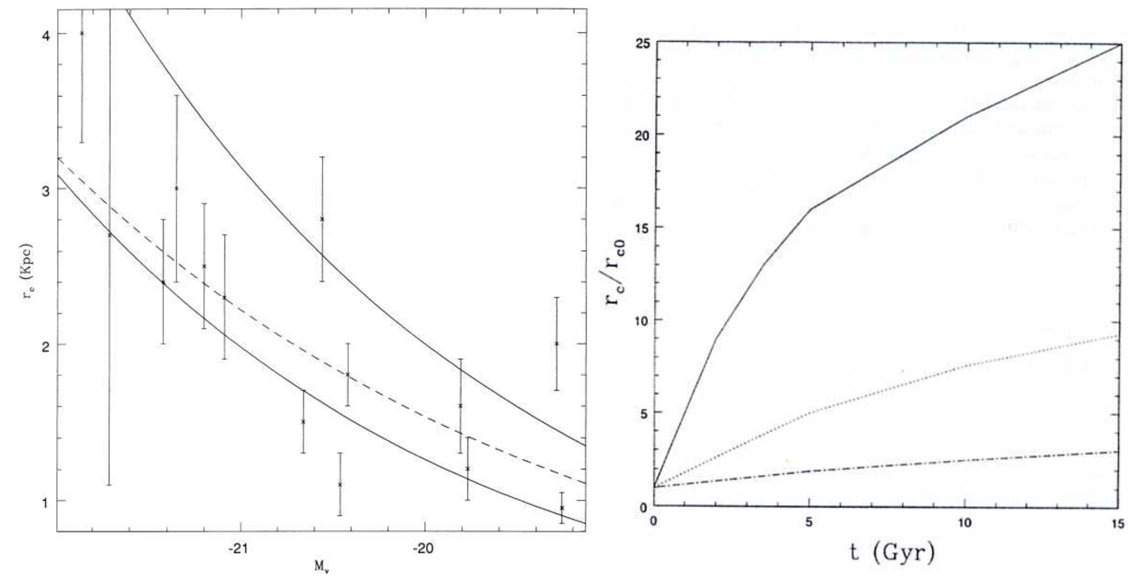

FIGURE 3. Left panel: GCS core radius as a function of the absolute integrated V mag. of the parent galaxy. Dots refer to data in [17], with their best fit as dashed line. Solid lines are two evoltionary models, with two different initial value of the GCS core radius (figure taken from [13]). Right panel: time evolution of the core radius of the GCS in a triaxial galaxy containing a central bh of mass (from bottom up) 10^7, 10^8, 10^9 $M_\odot$ (figure taken from [12]).

(ii) after $\sim$ 500 Myr many GCs, sufficiently robust to tidal deformation, are limited to move in the inner galactic region where they merge and form a Super Star Cluster (SSC);

(iii) stars of the SSC buzz around the nucleus where some of them are captured by a bh sitting there, partly increasing the BH mass;

(iv) part of the energy extracted from the SSC gravitational field goes into electro magnetic e.m. radiation inducing a high nuclear luminosity up to AGN levels.

Point (i) has been carefully studied in [26] and [14] in self consistent models of triaxial core-galaxies, and presently under study in triaxial cuspy-galaxies with dark matter haloes [10]. The validity of point (ii) has been demonstrated by first results of [4], while the resistance to galactic tidal forces of sufficiently compact GCs confirmed by [23] and the actual formation of an SSC via orbitally decayed cluster merger has been proved by detailed N-body simulations [15], [24]. Points (iii) and (iv) deserve a deeper investigation by mean of accurate modeling, even if they seem reasonably well supported by previous studies [4],[7].

CONCLUSIONS

Various papers by our research group have shown that many of the observed GCS features find a natural explanation in terms of evolution of a GCS in the galactic field, assuming the (very conservative) hypothesis that GCs were initially radially distributed as the galactic stellar component and coeval to it. In other words, no *ad hoc* assumptions

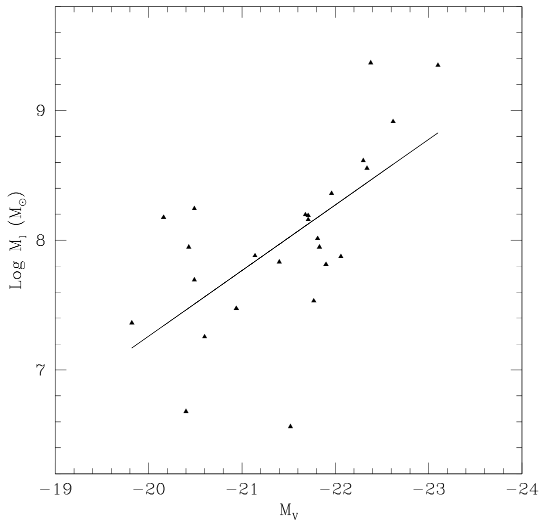

FIGURE 4. Left panel: Mass lost from the GCS vs. the integrated galaxy magnitude. Right panel: Mass lost from the GCS vs. the central black hole mass.

are needed to explain, for instance, the difference, observed in many galaxies, among the GCS-halo star profiles. The initial presence of some massive GCs ($M \geq 5 \times 10^6$ $M_\odot$) lead to the formation of a central SSC via merger of these orbitally decayed massive clusters. The SSC mixed it up with the galactic nucleus in which is embedded and constituted a mass reservoire to fuel and accrete a massive object therein. Observationally, this latter picture is supported by the observed positive correlation between the estimated quantity of mass lost by a GCS in galaxies and the mass of their central BHs (see Fig. 1 in [5]). On the theoretical side, the precise modes of mass accretion onto the BH via star capture from the merged SSC still remain to be carefully investigated.

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